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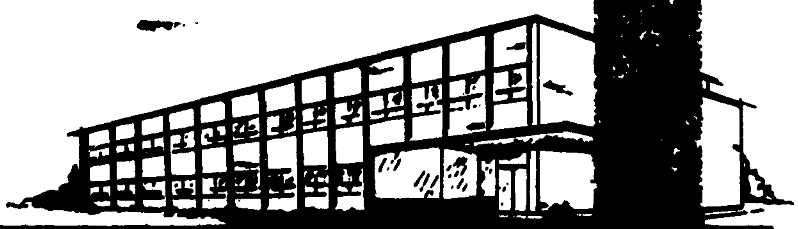

THE Bendix CORPORATION

BENDIX SYSTEMS DIVISION · ANN ARBOR, MICHIGAN

BSR 667

INTERIM ENGINEERING REPORT NO. 3

ANTENNA WINDOW

A TECHNIQUE FOR PROPAGATION

THROUGH A PLASMA SHEATH

1 December 1961 - 1 March 1962

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BENDIX SYSTEMS DIVISION
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Ann Arbor, Michigan

ABSTRACT

A double microwave reflectometer probe was designed and developed for measuring the properties of dense plasmas. This has been used to measure the properties of plasmas having up to 10^{16} electrons/cm^3 and collision frequencies up to 10^{12}/sec. Both the system and its theory of operation are discussed. Measurements of the affect of a magnetic field on the transmission and reflection characteristics of a plasma slab were made. The measured values of transmission-loss check well with those predicted from the measured plasma properties and linear theory while the reflection coefficient is a function of power level. A theoretical justification is given for this linear transmission-nonlinear reflection phenomenon. The curves of stagnation point N, ν and shock stand-off distance given in the Interim Engineering Report #2 were extended to a 50 lb Trailblazer II payload. Design of the instrumentation for the forthcoming flight tests was begun.

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SECTION 1

INTRODUCTION

During the past quarter, a double microwave reflectometer probe was developed and has been used to measure the properties of plasmas having up to 10^{16} electrons/cm^3 and collision frequencies up to 10^{12}/sec. The theory of operation of this device is discussed.

A theoretical study was made of non-linear plasma microwave interaction. It was found that the transmission characteristics of a uniform plasma slab should behave linearly for the power levels of interest in the laboratory and flight test experiments, while reflection from the slab may be a function of rf field strength for low and moderate power levels.

Measurements were made of the affect of a magnetic field on the transmission and reflection properties of a plasma slab. It was found that the measured values of transmission loss correspond closely to the values predicted from the measured plasma properties and the linear theory. However, the measured reflection coefficients do not agree well with the predicted values for moderate power levels. It is felt that this may be due to nonlinear plasma behavior; this possibility is presently being studied. A sample of the data is presented and discussed; the remaining data will be studied further and presented in the next report.

The curves of collision frequency, plasma frequency, and shock standoff distance given in Interim Engineering Report #2 have been extended to a payload of 50 lbs. These curves and the previous curves for a 20-lb payload should bracket the range of interest for the forthcoming flight test.

Design was begun on the instrumentation for the flight test. A beacon is being considered for the transmitter. This will be light-weight and may serve as a beacon until blackout sets in; after that time it would be pulsed internally. A second antenna may be used, with the transmitter

being switched between it and the antenna window radiator to remove the ambiguity as to whether one or neither of the antennas are blacked out. Provision may be made to vary the magnetic field strength with altitude. This would allow the product of attenuation constant and plasma thickness to be minimized, and hence, total transmission loss to be minimized.

SECTION 2

DISCUSSION OF PROGRESS

2.1 MICROWAVE PLASMA MEASUREMENTS

During the past quarter, a double microwave reflectometer probe was developed for measuring the properties of dense plasma. To date, plasmas having electron densities up to $10^{16}/cm^3$ and collision frequencies of $10^{12}/sec$ have been measured. These results were corroborated by measurements of propagation through a magneto plasma; the actual attenuation loss checked closely with that predicted from the measured plasma properties.

Theoretical considerations of non-linear effects indicate that the plasma attenuation characteristics should behave linearly for any power level of interest in the laboratory and flight test experiments, while the reflection characteristics may behave non-linearly for moderate power levels. It is believed that the non-linear reflection behavior occurs in the magnetic window measurements, though, because of the low power used, not in the reflectometer measurements of plasma properties.

2.1.1 Reflectometer Measurement of Plasma Properties

2.1.1.1 The Double Microwave Reflectometer

The microwave reflectometer, shown schematically in Figure 2-1, is basically quite simple: the variable attenuator in the secondary arm of the forward coupler is adjusted so that the "direct" output is equal to the "reflect" output when the plasma is a perfect reflector. For highly reflective plasmas, the difference of the two signals, which is proportional to 1-R for square-law operation of the crystals (R is the power reflection coefficient of the plasma) is then displayed and photographed; only the reflect output is displayed when the plasma's reflection coefficient is initially below about 0.9. This technique reduces the oscillogram reading error.

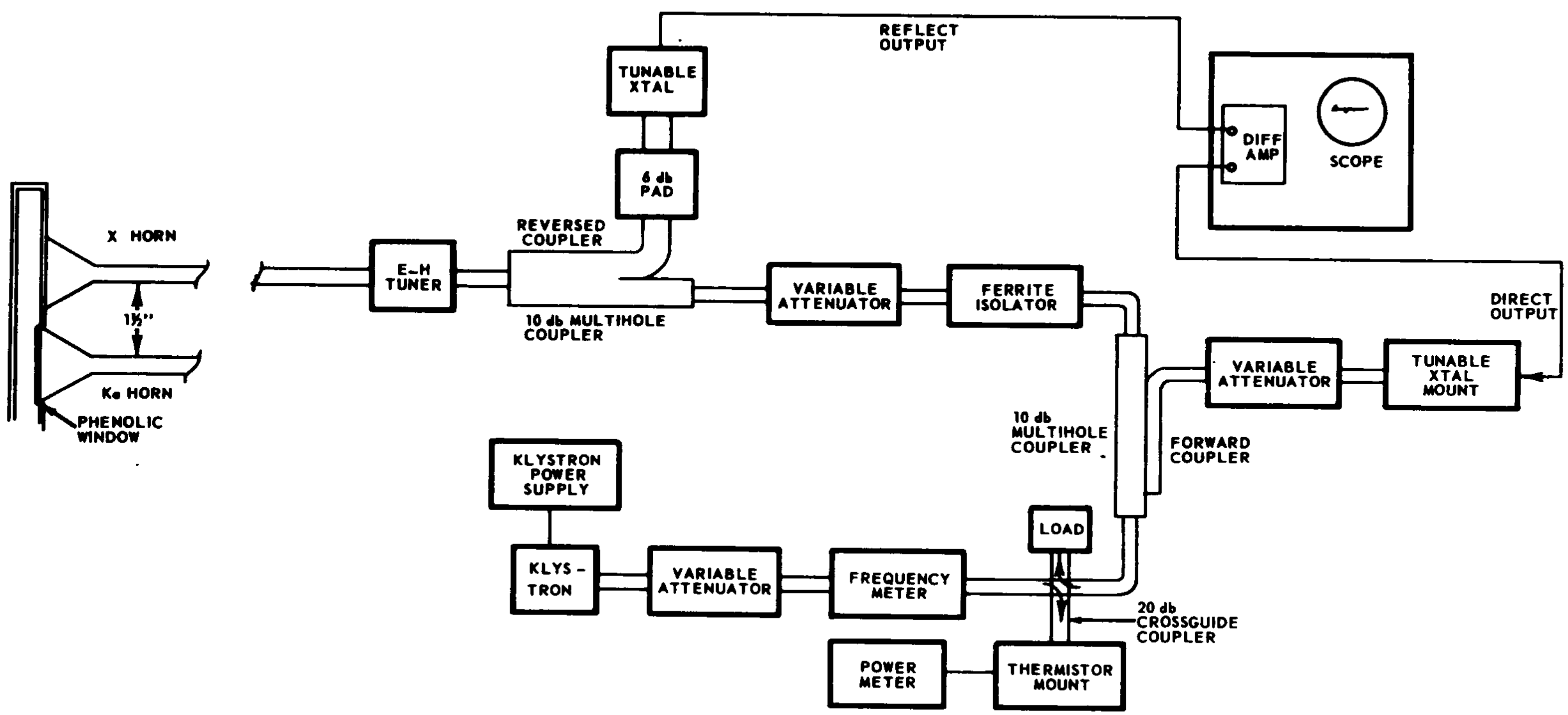


Figure 2-1 Schematic of X and Ka Band Reflectometer Probes

Despite the apparent simplicity of this device, careful attention must be given to the following factors if good accuracy is to be attained.

1. Signals other than that reflected from the plasma will reach the reversed coupler detector, thereby giving an output which is not proportional to the plasma reflection coefficient. This error will be a function of the phase of the plasma's reflection coefficient, which may vary from 0^{o} to 180^{o}. Thus, the error cannot be simply subtracted vectorally, since the phase of R cannot be known a priori.

2. The output of the forward detector will generally vary with R for the reason discussed in (1). If the power source is not isolated from the remainder of the system, its operation will also be affected by the plasma.

3. Some of the energy reflected from the plasma will be scattered past the horn, and, if this is not compensated for, the reflected signal will not be indicative of R.

The variation of the direct output with R was remedied by placing a ferrite isolator in front of the forward coupler. This reduced the variation from several percent (with an isolated klystron) for 180^{o} change of phase of a variable short, in place of the horn, to an unobservable variation.

Reduction of error in the reflect output was considerably more difficult. Reflection from the front glass wall of the shock tube test section was reduced to a VSWR of less than 1.02 by the use of an E-H tuner. The highly reflective ferrite isolator was matched by placing a variable (vane type) attenuator in front of it and adjusting the attenuator for the best match; a VSWR of 1.03 was obtained by this means. It was found that a 6 db fixed attenuator in front of a variable short crystal mount, tuned to maximum output, yielded better results than an E-H tuner in front of the crystal mount. The importance of the precautions can be seen from the fact that the reflect output varies less than 1% for 180^{o} change of phase of a short, in place of the E-H tuner and horn, for the configuration of Figure 2-1. Without the variable and fixed attenuators, the variation is over 100%.

The scattering loss was measured by placing a copper sheet on the glass over the horn, and then directly on the horn, and subtracting the reflect output reading of the first case from that of the second. The horn

was matched to the glass by the E-H tuner in the first case and to air in the second case. It was found that X band scattering loss was about 1% of the total energy and Ka band loss was 31%. A thin, 0.030 inch, window of fiber glass filled phenolic was inserted in the glass, and the Ka scattering loss was reduced to approximately 1%.

A further reduction of scattering loss error, as well as other errors, is obtained through the calibration procedure used. A 4-inch long piece was cut from an extra glass test section and fitted near one end with a phenolic plug identical to the one used in the shock tube.

The inside of the section was filled with Wood's metal to provide a reflector which simulates, except for phase, a perfectly reflecting plasma. The two reflectometers are placed in front of this short in the same relative position that they will have in the actual measurements (about 1 1/2" apart). The two outputs of each probe are fed into a differential amplifier, and the variable attenuators in the forward couplers are adjusted for zero amplifier output. By this technique, at least a portion of energy lost by scattering will be compensated for; i.e., the amount scattered by a perfectly reflecting plasma which completely fills the tube. If the plasma is not perfectly reflecting, but fills the tube, the scattering loss will still be nearly compensated for since it will be roughly proportional to R; there will be some divergence from perfect compensation due to the scattering from plasma elements below the surface. When the plasma does not fill the tube, the scattering loss can be considerable. However, as will be discussed in Section 2.1.1.2, there are short intervals during the runs in which the plasma very nearly fills the tube; it is at these times that the data are taken.

A study of the phase of R for the plasma properties measurable with the double reflectometer (See Section 2.1.1.2 for a discussion of this range) shows that it varies between 140° and 180°. Thus, since the phase of the short used in setting up the reflectometer is 180°, the error due to a phase variation of the reflected signal will be smaller than the 1% for 180° of phase shift.

2.1.1.2 Theory of Operation of the Reflectometer.

The reflectometer measurement consists of obtaining R for the plasma at two frequencies and deducing ν and ω_p, collision frequency and plasma frequency, from a suitable theory. This process is performed

graphically with the aid of the plot of ν/ω and ω_p/ω vs. 1-R shown in Figure 2-2. The representation shown was simply obtained by computing 1-R as a function of ν/ω and ω_p/ω, plotting the results with ω_p/ω as a parameter and then crossplotting. This technique is considerably less expensive than numerically solving the equation for R for ν/ω or ω_p/ω; it is probably not possible to solve for either of these analytically.

The data are reduced by placing a large (twice the size of Figure 2-2) transparent copy of this plot over a second copy. The two are positioned so that they are displaced along both axes by the frequency ratio of the probes. The plasma properties are then determined by the crossing of the two lines of constant R. Some of the lines have two crossing points; one at high ω_p and high ν, and the other at low ω_p and low ν. This ambiguity offers no practical problem since only the correct set of points gives consistent results as a function of time and from run to run.

The usable range of the double reflectometer probe corresponds to an area slightly smaller than the plotted part of Figure 2-1, with a frequency of 30 kMc. Toward the extreme right of the plot the lines have a constant slope of 45^o and the overlayed sets of lines do not cross. Below $\frac{\omega_p}{\omega} = 1$, R is too near to zero to be accurately measured; the area in the upper left corner is excluded by the inaccuracy of measuring reflection coefficients higher than about 0.99.

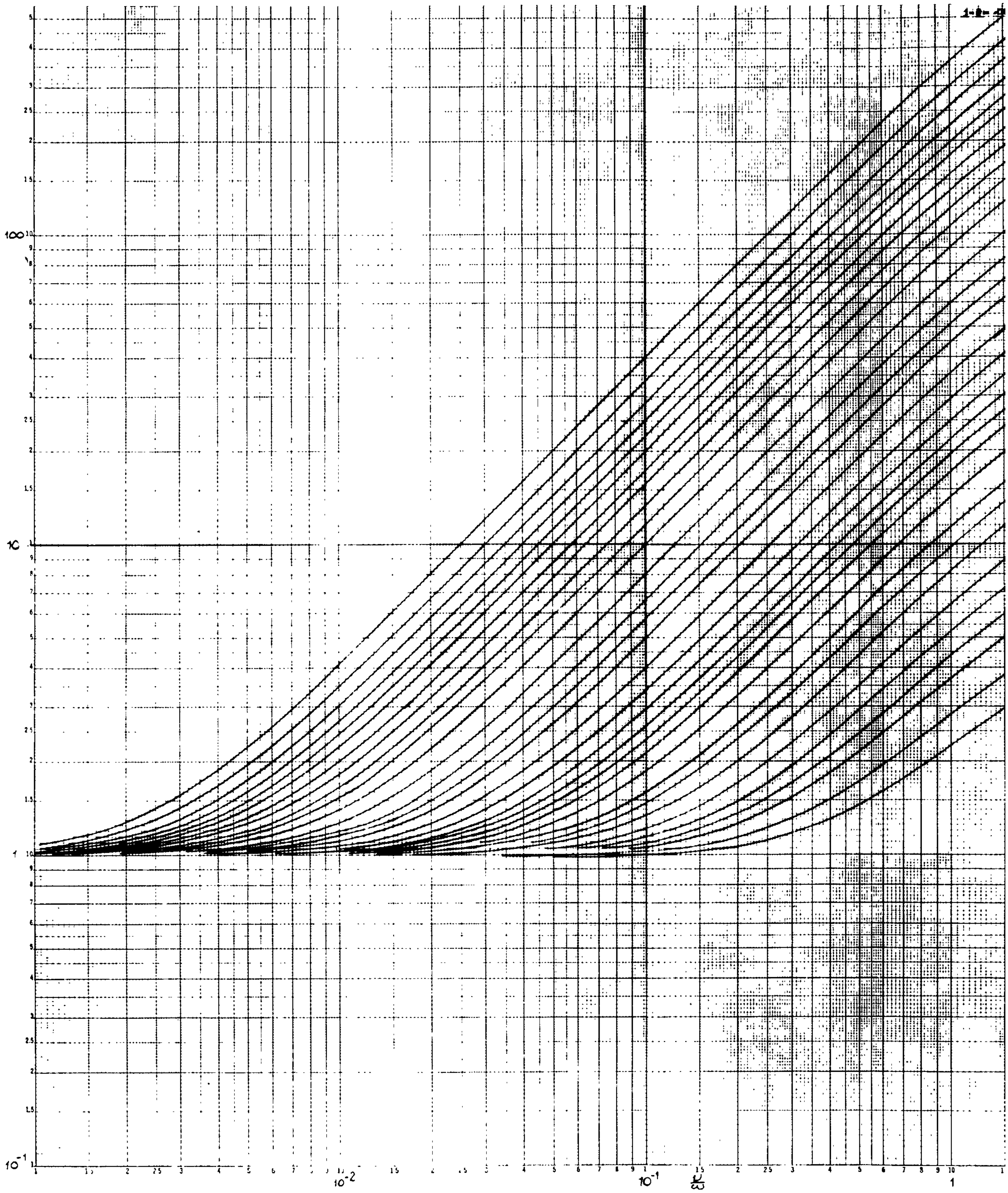
The following assumptions are used in the computation of R.

1. The plasma is a homogenous, semi-infinite slab having an abrupt interface with air.

2. The Appleton-Hartree theory describes the electromagnetic behavior of the plasma.

3. The incident wave is TEM and normally incident on the boundary.

These assumptions are discussed in the following paragraphs.



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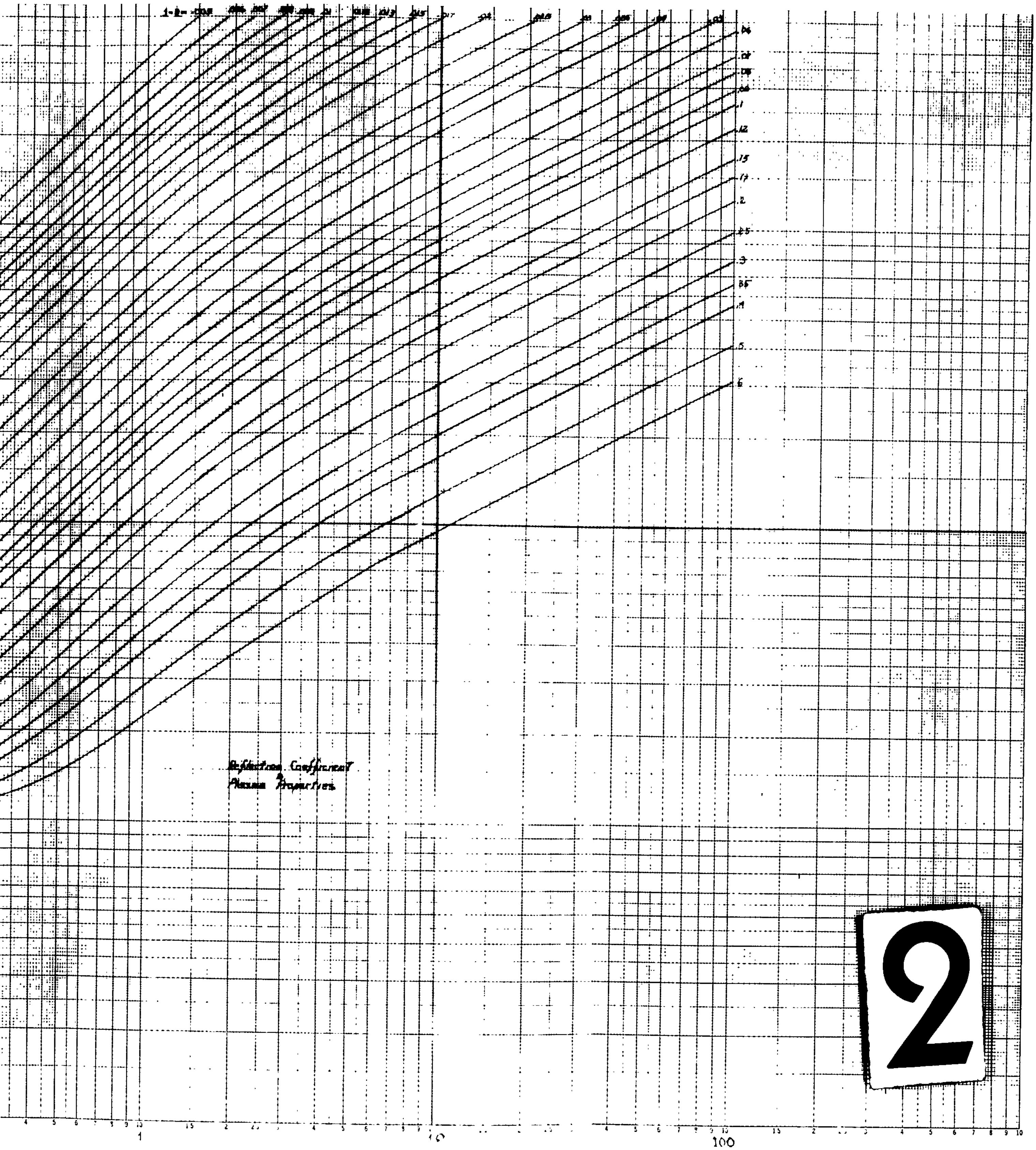

Figure 2-2 Reflection Coefficient vs Plasma Properties

1. Plasma Geometry

Neglect of the back boundary of the plasma in computing R is justified over the entire usable range of the double reflectometer probe since any contribution from the back boundary will be attenuated to a negligible value by the plasma. Considering the plasma to be a slab of infinite extent will be valid, since the horns are smaller than the flat portion of the test section, and since they are quite close to the plasma. The plasma is bounded by dielectrics, glass for X band, and phenolic for Ka band, which are one half-wavelength thick for each frequency; this is equivalent to the plasma being bounded by air, for low VSWR horns.

The most troublesome part of assumption (1) is the abrupt boundary. After the shock wave passes the observation point, the viscous boundary layer begins to grow; this results in velocity and temperature gradients at the walls of the tube. At the same time, the plasma recombines at the walls; both of these effects result in an electron density gradient at the wall and, subsequently, a diffuse boundary.

The end of the rectangular section is closed and flat, and is about 15 inches from the point of observation. Ideally, the reflected shock from the end will stagnate the plasma in the test section, eradicate the boundary layer, and homogenize the plasma, thereby restoring the abrupt boundary. However, the plasma boundary soon grows diffuse again due to plasma recombination at the walls. Measurements were made of the reflectometer scattered energy, discussed in Section 2. 1. 1. 1, and this ideal situation was found to be a good model for the actual case. The scattered energy increased with time after the initial shock wave passed the probes to a maximum of several times the metallic short value (increasing boundary layer). When the reflected shock wave arrived at the probes, the scattering loss dropped abruptly to approximately the metallic short value (indicating that the plasma inhomogeneity is nearly eradicated). The scattered energy increased again after the abrupt drop although more slowly than before the drop. This indicates a slower rate of growth of inhomogeneity from recombination at the walls than from recombination plus viscous boundary layer effects. The reflectometer measurements are made immediately after the initial shock passes, and again after the reflected shock arrives at the probes.

2. Plasma Theory — Nonlinear Effects

The basic assumption of the Appleton-Hartee theory is that all terms involving products of time-varying field quantities can be neglected in Maxwell's equations, and the equation of motion for electrons; i. e., that a system of linear equation can be obtained. This implies that the time-varying fields are perturbation quantities, so that terms involving products of these quantities can be neglected and the equation of motion can be linearized. It also implies that the plasma's properties, ν and N (electron number density), are independent of field strength; this makes Maxwell's equations a linear set, and makes the collisional term of the equation of motion linear. The equation of motion may be written as follows:

$$\frac{\partial \vec{v}}{\partial t} + \vec{v} \cdot \nabla \vec{v} = \frac{e}{m} \left[\left(\vec{\xi} + \vec{E} \right) + \vec{v} \times \left(\vec{\beta} \left(\vec{\xi} \right) + \vec{B}_o \right) \right] - \nu \vec{v} \tag{2-1}$$

where $\vec{\xi}$ and $\vec{\beta}$ are the electromagnetic fields and $\vec{E}$ is all other contributions to the electric field, such as change separation. $\vec{B}_o$ is the applied stationary magnetic field.

The non-linear term $\vec{v} \times \vec{\beta}\left(\vec{\xi}\right)$ may be neglected in this case since $|\vec{B}_o| >> |\vec{\beta}|$, for the antenna window, for any power level of interest.

The term $\vec{v} \cdot \nabla \vec{v}$ may be neglected if

$$|\vec{v}| << \omega L \tag{2-2}$$

where L is a distance representative of the inhomogeneity of $\vec{v}$. If the fields and plasma are homogeneous, $L \to \infty$ and there is no limit on the magnitude of v (except the relativistic limit $|\vec{v}| << c$). For a monochromatic plane electromagnetic wave in a homogeneous plasma, $L = \frac{\lambda}{2\pi}$, where λ is the RF wavelength in plasma, and Equation 2-2 becomes

$$|\vec{v}| << Vph \tag{2-3}$$

where Vph is the wave's phase velocity in the plasma. In general, the circularly polarized wave which will be propogated when a magnetic field is applied to the plasma will have a phase velocity less than c, and

approaches c as the field strength goes to infinity. For the range of plasma properties and magnetic field strength of interest in these experiments, Vph will be within one or two orders of magnitude of c.

The upper limit of electric field strength may be estimated by considering an electron in a sinusoidally varying electric field. Its velocity is given by

$$|\vec{\upsilon}| = \frac{e|\vec{E}|}{\omega m} \tag{2-4}$$

Invoking Equation (2-3) with 10^{-2} c on the right-hand side gives

$$|\vec{E}| << 10^{-2} \frac{\omega mc}{e} \approx 10^{-4} \text{ f volts/m.} \tag{2-5}$$

Thus, for 10 kMc the electric field strength must be much less than 10^6 volts/m or, in free space, the power must be much less than 10^9 watts/m^2.

If the plasma is inhomogeneous, L may depend on the dimensions of the plasma inhomogeneity: If the plasma changes greatly in a distance which is small when compared with a wave length, e. g., at a boundary, then L will involve the dimension of the inhomogeneity. If the plasma changes but little over a wavelength, L will be $\frac{\lambda}{2\pi}$. Thus, the reflective behavior of a plasma sheet may be non-linear while the transmission properties are behaving linearly.

These considerations yield an upper limit on $|\vec{E}|$ since $\vec{\upsilon}$ will generally not be co-linear with $\nabla \vec{\upsilon}$, as was assumed above. In fact, if a plane wave is purely transverse to the homogeneous field $\vec{B}_0$ and the plasmas varies only in the direction of propogation, then $\vec{\upsilon} \cdot \nabla \vec{\upsilon}$ will vanish identically, and will impose no restrictions on $|\vec{\upsilon}|$. Also, the presence of heavy particles and $\vec{B}_0$ will result in a lower value for $|\vec{\upsilon}|$ than that given by Equation (2-4).

The non-linear behavior due to the dependence of ν and N on $|\vec{E}|$ has been recently studied by Ginzburg and Gurevich[1]. They explain

[1] "Non-linear Phenomena in a Plasma Located in an Alternating Electromagnetic Field"; V. L. Ginzburg and A. V. Gurevich; USPEKHI; Part I: July-Aug. 1960, Vol 3 no. 1; Part II; Sept-Oct, 1960 Vol 3 no 2.

the mechanism as one in which the electrons gain more energy from the field in a mean free path than they can lose in a collision with a heavy particle. The electrons thus continue to gain energy, randomizing it by colliding with other particles, until a sufficient number of the collisions are inelastic, (ones in which electrons can transfer a large percentage of their energy to a much heavier particle) and equilibrium is reached, (i. e., ν increases until the electrons can transfer the energy gained in a mean free path.) These inelastic collisions yield new electrons, and therefore, N as well as ν is a function of $|\vec{E}|$. Past a certain value of $|\vec{E}|$ no equilibrium is possible and the plasma breaks down. The criterion for the neglect of this type of non-linearity is the following:

$$|\vec{E}| \ll 4.2 \times 10^{-8} \sqrt{\delta T (\omega^2 + \nu_o^2)} \text{ volts/m} \qquad (2\text{-}6)$$

where T is the absolute temperature of the plasma in ^oK, δ is the fraction of energy lost, on the average, by electrons to heavy particles, and ν_o is the collision frequency for zero field. For elastic collisions between two masses m and M, M >> m.

$$\delta = \frac{2m}{M} \qquad (2\text{-}7)$$

This is roughly 3×10^{-5} for air. For inelastic collisions this can be unity for an individual collision; the average value may be above 0. 3.

An upper limit on $|\vec{E}|$ can be obtained by assuming that all collisions are elastic and that $\delta = 3 \times 10^{-5}$. The value of T can be estimated from the curves shown in Figure 2-3. These were obtained by cross-plotting a curve for ν vs ρ/ρ_o and T from Musal[1] and N vs ρ/ρ_o and T from Gilmore.[2]

It is seen that a conservative value for T is 4×10^3 ^oK. Using these values for δ and T in Equation (2-6) yields:

$$|\vec{E}| \ll 1.46 \times 10^{-8} \sqrt{\omega^2 + \nu_o^2} \qquad (2\text{-}8)$$

Considering the worst case, $\nu_o = 0$, gives

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1 Henry M. Musal, Jr., "Electron Collision Frequency in Equilibrium High Temperature Air," Research Note 9, Bendix Advanced Development Laboratories, 1 May 1960.

2 F. R. Gilmore, "Equilibrium Composition and Thermodynamic Properties of Air to 24,000 ^oK," the RAND Corp., RM-1543, 24 August 1955.

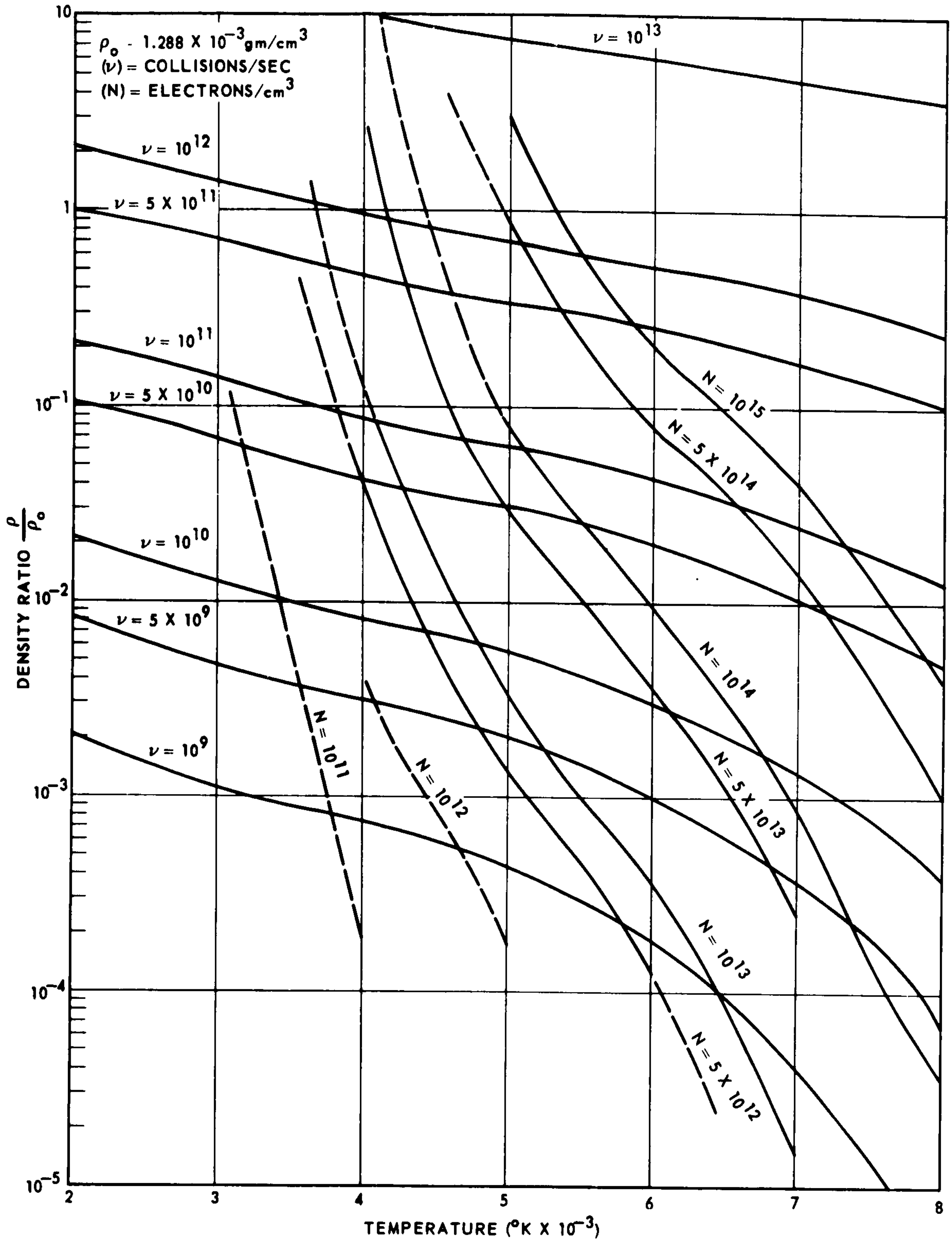

Figure 2-3 Plasma Properties vs Temperature and Density Ratio

$$\left|\vec{E}\right| << 1.46 \times 10^{-8} \omega \ \frac{\text{volts}}{m} \ (\nu \underset{o}{=} o) \qquad (2\text{-}9)$$

For X band (10 kMc), $\left|\vec{E}\right| << 10^3$ v/m which corresponds to a power, in freespace, of 1200 watts/m^2.

Since the plasma near the walls of the test section will be colder than that near the center, the plasma's reflection coefficient is more likely to vary with $\left|\vec{E}\right|$ than is its attenuation constant. The reflectometer probes are therefore operated at as low a power as possible. With the present setup this is from one to two milliwatts (from 0.4 to 0.8 watts/m^2).

3. The Electromagnetic Field

Of the three assumptions, (3) is perhaps the least realistic. The actual field is the near field of a waveguide horn. Other methods of illuminating the plasma were considered, including the use of lenses and open waveguide placed against a thin dielectric window. Lenses are still being considered but may not be usable because of the relatively large scattering loss (this might be a function of the plasma properties, and if so, would be impossible to compensate for accurately.)

An open-ended waveguide fitted into a metallic wall of the test section, and covered with a thin dielectric window to keep the plasma boundary sharp, would look like a small waveguide opening into an infinite plasma filled guide. Curves such as Figure 2-2 could then be plotted, and ν and N could be determined. If the simple equation involving the ratio of the sums and difference of the waveguide impedances can be used, the computation will be quite simple. However, the error in this equation is probably intolerably large, and a more exact formulation must be used. In either case, a set of curves would have to be computed for each frequency. This method is still being considered for the ultimate reflectometer setup.

At this point, it bears repeating that the double reflectometer-probe measurements check well with the magnetic field propagation measurements, which do not depend as much on the exact field configuration as do the reflection measurements.

2.1.1.3 Reflectometer Data

Figure 2-4 shows a typical oscillogram of the double microwave reflectometer data. The upper trace is the Ka band reflected signal, 30 kMc, and the lower trace is X band, 10 kMc, reflected signal. Two centimeters deflection is equal to 100% reflection, and the sweep rate is 200 $\mu s/cm$. The initial value of the upper trace is due to reflections from the back of the test section. The growth of plasma inhomogeneity and its eradication by the reflected shock wave is evident in this record. Both traces rise, after several small pertubations, to maximum values soon after the initial shock wave passes the probes; these values of R correspond to $N=7.1 \times 10^{14}/cm^3$ (fp = 240 kMc), and $\nu = 10^{11}$. The Ka reflection drops faster than the X-band reflection because the boundary diffusity is a greater fraction of a Ka band wavelength. The reflected shock returns after approximately 500 μs as seen by the fast rise of the Ka trace; the identity of this rise with the arrival of the reflected shock was verified by the search coil experiment described in Interim Engineering Report #1. The plasma properties were measured immediately after the reflected shock arrival and were found to be $N=2.2 \times 10^{14}$ and $\nu=0.81 \times 10^{11}$; these values correspond to the stagration point plasma for a 50 lb Trailblazer II re-entry at 125 Kilofeet. Attenuation loss at 10 kMc was computed to be 13.3 db for these values and for a magnetic field of 27.5 kilogauss. The measured value varied between 11 and 14 db in the several runs made.

The double reflectometer probe has been used to measure plasma properties up to $N=10^{16}/cm^3$ and $\nu=10^{12}$.

2.1.2 Magnetic Window Measurements

Figures 2-5a and 2-5b are oscillograms of the magnetic field measurements of transmission and reflection from the plasma described in Section 2.1.1.3. The upper trace of Figure 2-5a shows reflection and the lower trace transmission. The time base is 200 $\mu s/cm$. The magnetic field is applied after the return of the reflected shock wave to avoid possible alteration of the plasma by the field (see Interim Engineering Report #1 for a discussion of a possible effect of the magnetic field on the plasma).

The wave is circularly polarized so that the ordinary and extraordinary waves may be studied individually. The magnetic field was initiated at t=550 μs and it reaches its first maximum of 27.5 kilogauss at t=600 μs.

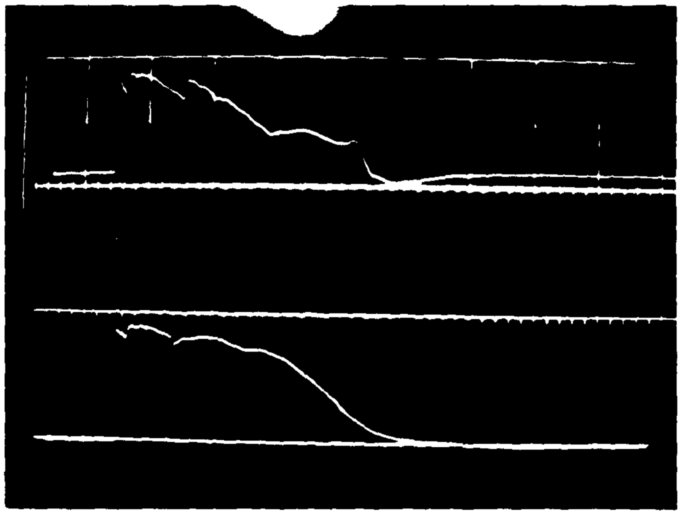

Figure 2-4 Double Reflectometer Probe Oscillogram

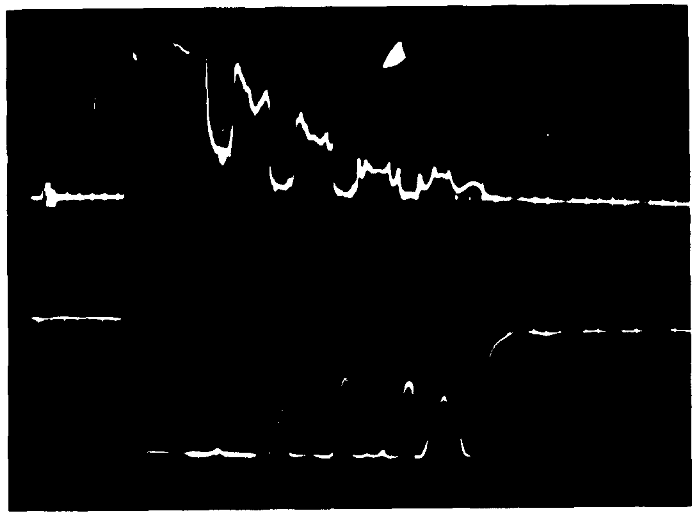

Figure 2-5 (a) X-Band Reflection and Transmission Through a Plasma Slab in a Magnetic Field

Figure 2-5 (b) Expansion of First Transmission Pulse

At this time, the transmission increases from complete blackout, a predicted attenuation of 248 db, to 14 db below full transmission, as seen by the first bump in the lower trace of Figure 2-5a. In Figure 2-5b the first transmission peak for an identical run is displayed in the upper trace on a time base of 20 μs/cm; this trace is initiated by the pulse which fires the field-coil capacitor bank.

The effect of the magnetic field on the reflection coefficient is clearly seen in Figure 2-5a. At the first field peak, R is reduced to 0.21 or 0.83 db reflection loss per boundary. Subtracting twice this value from the total loss yields an attenuation loss of 12.4 db. As mentioned previously, the loss predicted from the measured plasma properties and the linear theory is 13.3 db.

The next half cycle of the magnetic field produces no transmission peak since the direction of the field is unfavorable for transmission; the computed attenuation is 115 db for this case.

Although the transmission loss agrees well with that predicted from the linear theory, the reflection loss is in error by a factor of two; the computed value for R is 0.45. This might be due to the non-linear effects mentioned in Section 2.1.1.2, since lower power levels yield higher values of R; the power density of this run was about 10 mw/cm^2. This effect is presently being studied. It is possible that this might be used to further decrease telemetry power losses during re-entry.

These measurements are being made over several orders of magnitude of N and ν.

Care was taken to eliminate from the data voltages induced by the magnetic field discharge. This was done by DC isolating the crystal mounts and by the use of bucking coils. Direct Current isolation of the crystal mounts reduced the pickup from a point where it was strongly affecting the crystal operation, (several volts) to where it amounted to a few millivolts. The remainder is canceled by feeding the crystal output into one input of a differential oscilloscope preamplifier and the output of a coil of wire into the other; the coil output is adjusted by a variable resistor so that the pickup on the crystal output, and within the oscilloscope, is canceled.

The transmission probe used in these measurements is shown schematically in Figure 2-6.

Resistive elements were placed in the H-plane of the rectangular to circular transitions to make the polarization of the wave independent of the plasma reflectivity. A wave which is circularly polarized initially would be partially reflected by the plasma, shifted an additional 90°, and emerge from the phase shifter at right angles from the entering wave. It would be totally reflected from the rectangular wave guide at the end of the transition, pass through the phase shifter, and assume the opposite polarization it had before being reflected from the plasma. Thus, the wave entering the plasma will be elliptically polarized by an amount determined by the plasma. The resistive elements attenuate the reflected wave to a negligable value, while having little effect on the incident wave. By this means, the dependence of the polarization on the plasma was made immeasurably small. The same precaution was taken with the receiver in order to eliminate error due to reflection from the detector.

A straight wire probe was inserted into the circular portion of the transition at right angles to the plane of polarization of the incident wave. This probe will, therefore, measure only the reflected wave which has its electric field in the direction of the probe.

The polarization was measured and the unwanted circular component was found to be 30 db below the desired component.

2.2 AERODYNAMIC ANALYSIS

The computations for ν, f_p, and shock stand-off distance were extended to a 50 lb Trailblazer payload. Figures 2-7 through 2-9 show these results and those for the 20 lb case given in Interim Engineering Report #2. It is felt that these two values for payload weight, bracket the range of interest for the forthcoming flight test. The computations for shock stand-off distance are given for a 6.75 inch nose-cap radius; this is a more realistic value than the 2.75 inch figure previously used.

2.3 FLIGHT TEST INSTRUMENTATION DESIGN

Work was begun on the design of the Trailblazer Instrumentation with consideration of the following possibilities:

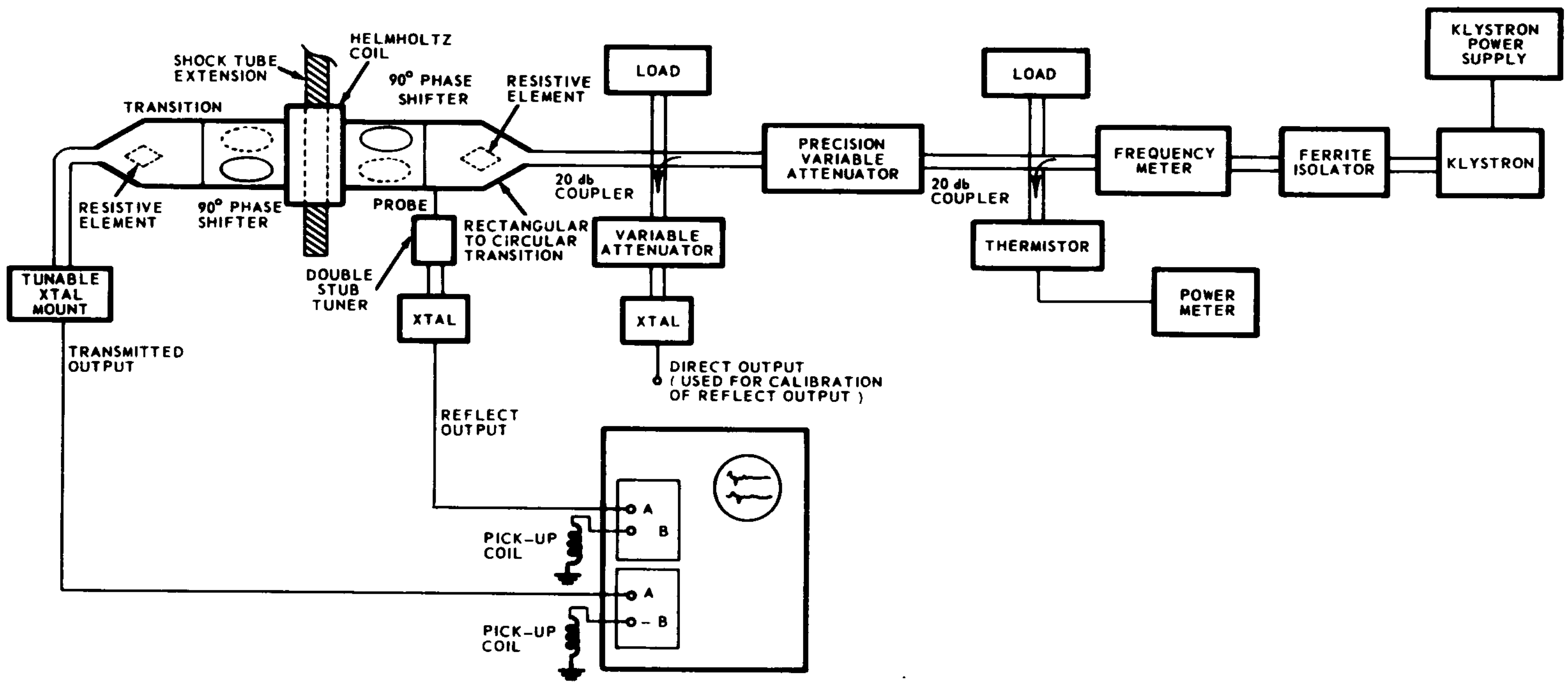

Figure 2-6 Magnetic Field Transmission Probe

1. An antenna should be placed near the magnetic window (but not in the strong field) in order to provide a basis of comparison for the antenna window operation. Switching the transmitter between the two antennas will remove the ambiguity whether one or neither of them are blacked out.

2. The telemetry transmitter might be an S-band beacon. This could be operated as a beacon by the ground tracking radar until communications blackout sets in; after that time it could be pulsed internally. This system would have the added advantage of being lightweight.

3. Provision might be made for varying the magnetic field strength as a function of altitude. This would permit a lower field to be used at high altitudes where the plasma is less dense and where the magnetic field strongly influences the shock stand-off distance.

Since the increase of shock stand-off distance due to the magnetic field is proportional to $|\vec{B}_o|^2$, while the attenuation constant is, at most, proportional to $\frac{1}{|B_o|}$, the total attenuation loss might be considerably reduced at high altitudes by using a lower field.

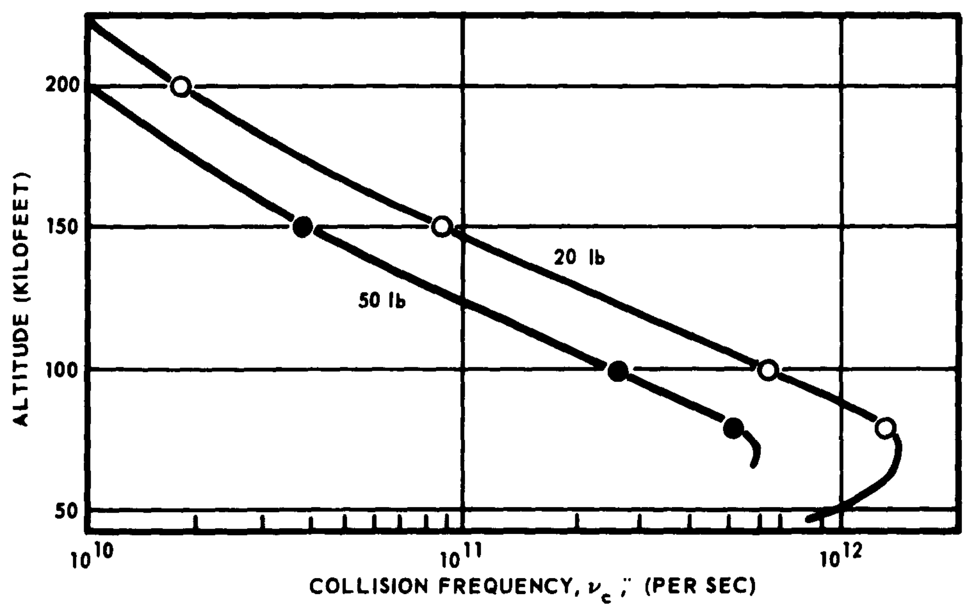

Figure 2-7 Stagnation Point Electron Collision Frequency

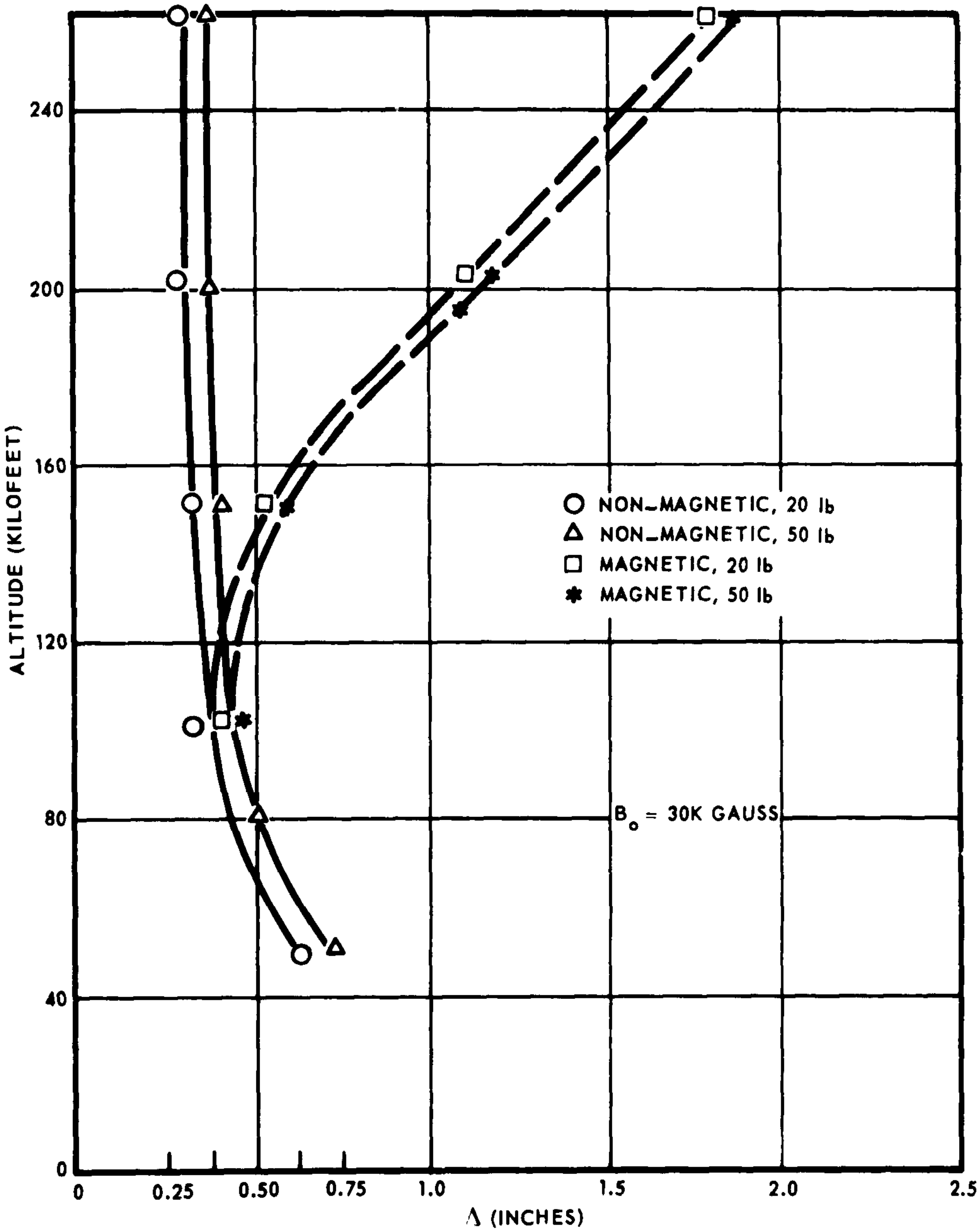

Figure 2-8 Shock Stand-Off Distance: Magnetic and Non-Magnetic Cases for a 6. 75 in. Radius Nose Cone Cap

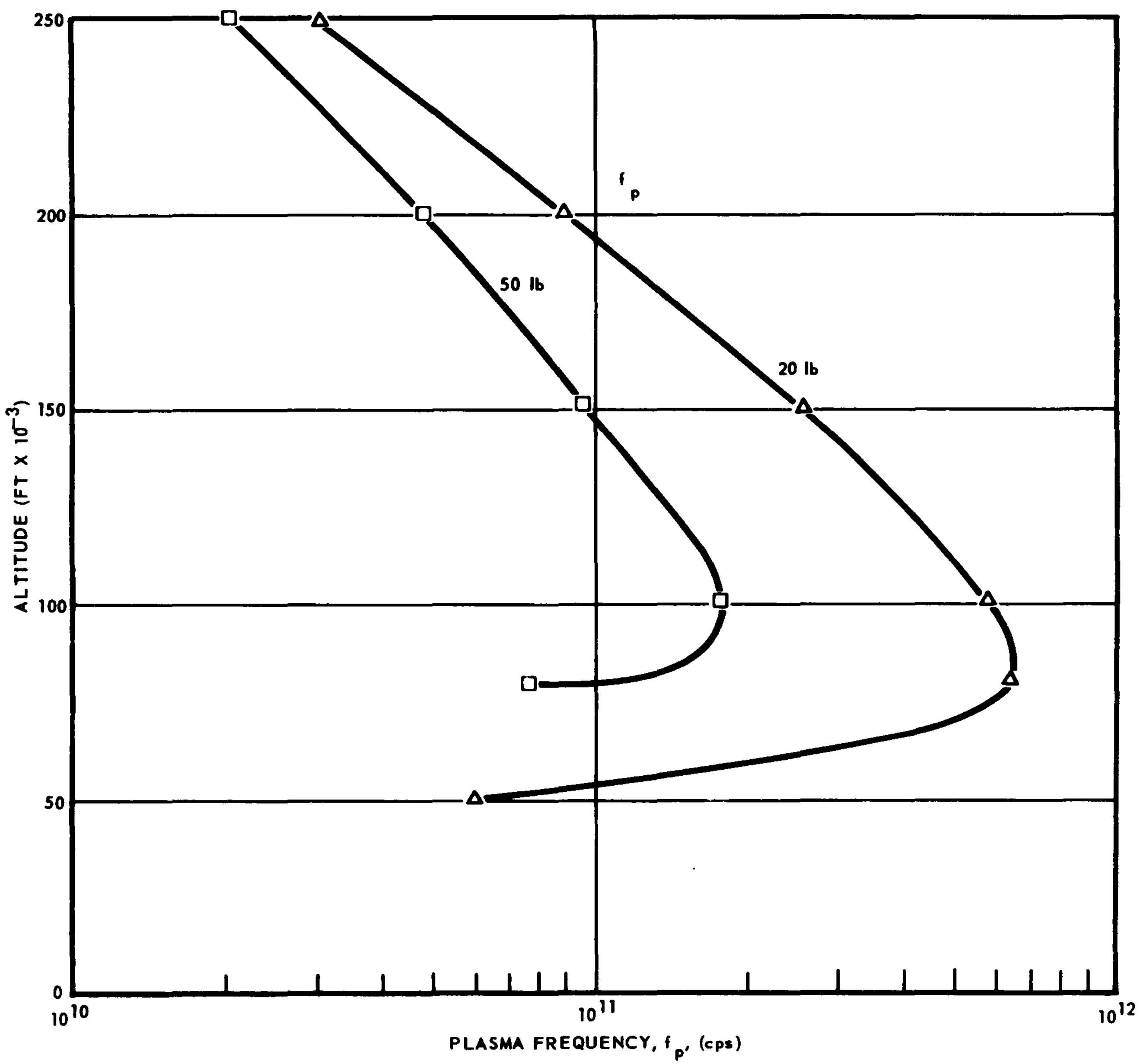

Figure 2-9 Equilibrium Plasma Frequency vs Altitude

SECTION 3

CONCLUSIONS

The reproducability of results and good agreement of predicted and measured plasma attenuation loss indicate that the double reflectometer probe is a useful diagnostic device for dense plasmas. Measurements have been made of plasma properties up to $N=10^{16}/cm^3$ and $\nu = 10^{12}$.

Measurements made of reflection and transmission characteristics of a plasma slab indicate that the reflection coefficient may be a function of rf power level for moderate powers, while the attenuation constant behaves linearly for relatively high power levels. This is being studied and may provide a means of minimizing reflection losses from the re-entry vehicle's plasma sheet, i.e., by a proper choice of frequency and power level.

The plots of N, ν, and shock standoff distance for the 50 lb payload indicate that the maximum blackout conditions will be somewhat less severe and will occur at a slightly higher altitude than the 20-lb payload case.

Total power loss may be minimized at high altitudes by the use of a lower magnetic field.

SECTION 4

PROJECT PERSONNEL

The following people have contributed to the progress discussed within this report:

K. Daren	Computation
R. DeLosh	Project Engineer
J. Halstead	Computation
C. LaPointe	Plasma Studies
R. Layton	Reflectometer Design and Shock Tube Experimentation
J. Maszatics	Aerodynamic Analysis
R. Moll	Electronics Technician
G. Thomas	Computation
D. White	Shock Tube Experimentation and Electronics Design